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BULLETIN No. 4. A. S. 6.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF AGRICULTURAL SOILS.

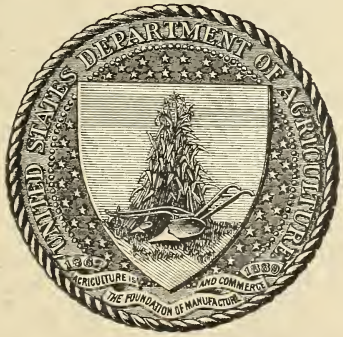
METHODS

OF THE

MECHANICAL ANALYSIS OF SOILS

AND OF THE

DETERMINATION OF THE AMOUNT OF MOISTURE IN SOILS IN THE FIELD.



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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS,
Washington, D. C., February 15, 1896.

SIR: I have the honor to transmit herewith a manuscript describing the methods in use in this Division for the mechanical analysis of soils and for the determination of the amount of moisture in arable soils.

This is intended partly for the instruction of the observers and special agents of this Division, and partly for the information of workers in the agricultural colleges and experiment stations and other institutions or organizations which are interested in similar lines of work and who wish specific information as to methods.

I recommend that this be published as Bulletin No. 4 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

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MECHANICAL ANALYSIS OF SOILS.

COLLECTING SAMPLES OF SOIL FROM THE FIELD.

The methods of collecting samples of soil should depend largely upon the nature of the work for which the sample is to be used. The purpose of this Division is to investigate the texture and physical properties and conditions of the soils of extensive agricultural areas and to establish the typical conditions prevailing therein which adapt them to certain crops or certain agricultural interests. Having established these general conditions as a basis for the study and classification of soils, it remains for local institutions to investigate soils of local interest in their respective States.

As a rule, then, it is necessary that the soils selected for examination or investigation by this Division should represent large areas of land of uniform composition and of similar agricultural value, and not merely a small area in which the observer is particularly interested. These conditions may be determined from native growths, or from cultivated crops, or from the general appearance of the land. For instance, in a wheat, corn, tobacco, or truck area the samples selected should represent the best type of land for those crops.

It is often advisable also to study soils and soil conditions unadapted to our present agricultural crops. Many large areas of land are at present barren and unproductive, and, under certain circumstances, it is advisable to investigate the texture and moisture conditions in these tracts.

These investigations are intended as permanent records of the typical conditions of the principal soil areas of the United States and the relative proportions of moisture which the soils maintain under prevailing climatic conditions.

WHERE SAMPLES SHOULD BE TAKEN.

In order that every sample may represent the area or a certain part of the area which it is desired to study, it must not be taken where there are modifications due to local conditions. It is better, where possible,

to take the samples from cultivated fields, or fields which have been cultivated. The agricultural value of such land is known from the character of the crop it has produced, and this is a very important guide in the selection of typical soil samples. In the older agricultural regions of the Eastern United States, especially in the most fertile soil areas, there is little or no virgin land and often little woodland. Where the trees are allowed to grow, it frequently happens that it is on some spot or area which has been abandoned for some local cause or which has never been brought under cultivation because of its small agricultural value. A sample taken in such uncultivated spots would not represent the typical soil area of the locality, whereas soil which has been under cultivation carries a record in its crop yield and in the character of the crop produced, which is an important guide in the classification of the lands.

The samples should be taken inside a field, some distance away from houses, fences, roads, or trees. If plants are growing in the field, the sample should be taken midway between two plants. They should not be taken where the soil has been eroded nor where the soil has accumulated to an unusual depth by washing from above. It is doubtless better to take the samples from land which has not been freshly manured or where fertilizers have not been recently applied, but if there is no such field available this need not prevent the taking of samples, for the purpose of the investigation is to study the conditions under which the plants are growing in the field under the ordinary operations of the farm.

For the study of local conditions, such as the soil of a single field or a single farm, samples should be taken from five to eight localities, at some distance from each other, according to the uniform character of the soil, thoroughly mixed together if the land appears uniform, and a small sample of this mixture taken to represent the average conditions of the field. If the land appears not to be uniform, the samples should be kept separate and examined separately. In the work of this Division, however, great soil areas of nearly uniform conditions are being studied and samples are taken over wide areas, irrespective even of State lines. A single sample may be sufficient from any one field, provided a sufficient number of widely separate localities are examined from the same formation, to give a basis for an estimation of the uniform character of the formation and to judge as to whether each individual sample represents truly the type of soil which it is desired to study.

The type having been established, a single sample, selected with care and judgment, is usually sufficient to determine whether the soil of that locality corresponds to the typical soil formation which it is desired to study.

HOW SAMPLES SHOULD BE TAKEN.

Having selected the spot in conformity with the above instructions, there are two reliable methods for collecting the samples—with a spade and with an auger. To collect the sample with a spade, remove all grass, leaves, or litter from the surface and dig a hole like a post hole 24 inches deep. Scrape the sides clean and notice the depth at which the change of color occurs between the soil and the subsoil. Take a sample of the soil above this by cutting off a slice of soil 3 or 4 inches thick, down to the change of color, and mix this thoroughly together. Fill a cloth sack with this well-mixed soil, tie it securely, and label it with such information as will serve to identify it when it is received in the laboratory. Then clean out the hole again and scrape the sides so as to get rid of every particle of the top soil, and take a sample of the subsoil in like manner by cutting down a slice of the subsoil and thoroughly mixing it together so that the sample shall contain particles of the subsoil from immediately below the top soil to a depth of at least 24 inches. Put this sample of the subsoil into a separate sack, tie it securely, and label it. If there is no apparent difference between the soil and the subsoil, take a sample of the soil nevertheless to a depth of 6 inches from the surface, and a sample of the subsoil from below this to a depth of 24 inches, and put them into separate sacks as above. If the character of the subsoil materially changes before the depth of 24 inches is reached, a separate sample of this changed material should be taken and the depth noted at which the change occurs.

To collect samples with an auger, take a common wood auger from $1\frac{1}{2}$ inches to 3 inches in diameter and have the handle lengthened to 24 or 30 inches. Remove the litter and grass as before from the surface of the field, and bore into the soil, pulling up the auger and emptying the sample into a sack for every 3 or 4 inches in depth. The depth of the top soil should be determined by a preliminary boring. Care must be taken to separate the top soil from the subsoil and to keep them in separate sacks. If there is a marked difference in the character of the subsoil within 18 or 20 inches of the surface, a separate sample should be taken of the second subsoil, the depth of each being carefully noted.

IMPORTANCE OF TAKING SAMPLES AT UNIFORM DEPTHS.

It is very important that the samples be taken, as far as practicable, to a uniform depth, to secure the greatest comparative value in the work. The plan adopted by this Division is to take the sample of top soil to a depth of at least 4 or 6 inches, or to the change of color where this is apparent within 9 or 12 inches of the surface. The subsoil is then sampled to a depth of at least 24 inches in the case of very stiff clays, and to a depth of 24 or 30 inches in the lighter soils.

An idea of the importance of taking samples to a uniform depth and

of stating this depth may be seen from the following table of mechanical analyses of samples of the Kentucky blue-grass land from Lexington, Ky. The samples were taken from a vertical hole, one directly under the other, at the depths shown in the table:

Mechanical analyses of Kentucky blue-grass soil.

Diameter (mm.).	Conventional names.	295 (0–6 in.).	296 (6–12 in.).	297 (12–18 in.).	298 (18–24 in.).
2–1	Gravel	0.00	0.00	0.00	0.00
1–.5	Coarse sand	0.00	0.11	0.00	0.00
.5–.25	Medium sand	0.14	0.12	0.11	0.07
.25–.1	Fine sand	0.28	0.16	0.15	0.11
.1–.05	Very fine sand	1.35	2.49	0.61	0.33
.05–.01	Silt	48.72	40.63	40.44	33.45
.01–.005	Fine silt	15.26	16.12	15.53	13.00
.005–.0001	Clay	25.49	33.42	37.28	44.95
		91.24	93.05	94.14	91.91
	Organic matter, water, loss	8.76	6.95	5.86	8.09

It will be seen that the percentage of clay is very different at these different depths, and the results of the analyses would have been very different in two samples taken side by side at different depths. It occasionally happens from the nature of the subsoil that the samples can not be taken to a depth of 24 to 30 inches. In any case, the actual depth represented by each sample should be stated—such as "0 to 6 inches;" "6 to 24 inches"—and a note made of the character of the sample.

SACKS FOR COLLECTING SOIL SAMPLES.

Three sizes of sacks are used by this Division for the collection of soil samples. When the samples are taken with a spade, 8 to 10 pounds of material should be collected and put into a cloth sack—14 by 8½ inches—of heavy, unbleached muslin. For samples taken with the auger, a smaller sack can be used, as the sampling is usually more accurately done. Sacks 6 by 8½ inches are very convenient for this purpose. As the sample of the top soil is usually smaller than that of the subsoil, and as it is usually of relatively less importance, smaller sacks, 4 by 6 inches, may be conveniently used for the sample of top (surface) soil. This is likewise a very convenient size to take on an expedition when a large number of samples are to be taken and when the weight of material is an important consideration. These sacks have short pieces of string or tape sewed to them for convenience in tying, and they should each be numbered with a stencil for convenience in referring to them in the field notes.

Each sample should be carefully labeled on a tag prepared for the purpose, to be tied to the sack. This may be conveniently printed on one side of a shipping tag, with the name of the institution or individual printed in bold-faced type on the other side. The samples are heavy and bulky, and are usually moist, so that it requires a very strong and tough tag to stand the wear. It is important to use either linen tags or the tough red express tags.

FORMS FOR DESCRIPTION OF SAMPLES.

The following form has been adopted for use by this Division where samples are sent in by field agents of the Department or by farmers:

Locality:	
No. of sack:	Description of land: (*a*) Virgin or cultivated? (*b*) Natural herbage:
Date:	
Collector:	(*c*) Class of crops best adapted to land (grass, wheat, corn, tobacco, truck, barren):
Depth of sample: Soil or subsoil? ....in. to....ins.	Geological formation:

In sampling with the auger in a locality or in a formation which is already known, and where the samples are taken with great care, smaller tags may be conveniently used, there being less information to be added in the field. The following form is used for this purpose by this Division:

Name .....

Locality .....

Type (grass, wheat, corn, tobacco, truck, barren land).

Depth of sample, ... in. to .... ins.

Character of sample .....

.....

Geological formation .....

No. of sack .....

When the samples are sent from a locality which has not been carefully examined by agents of the Department, a very full report should be made to supplement that contained on the shipping tags. This should include the character of the soil and the staple crops which have been successfully grown upon it; the yield of the principal crops; the character of the crops; the effect unfavorable seasons have upon the crop. In a wet season are the plants liable to make an abnormal development? Are they subject to diseases? Does a dry season reduce the yield of the crop materially? Does it affect the quality of the crop? All the information bearing upon the relation of the soil to crops in different seasons should be given, so as to make possible an intelligent diagnosis of the soil conditions and throw light upon any peculiarities

which are manifested either in the actual relation of soils to crops in the field or in the laboratory examination of the samples. Such information, besides, may often point to causes controlling crop production apart from those existing in the soil and shown in the sample. As in the case of a sufferer from headache, the cause of the trouble may not be in the head at all, but in some other part of the body, so, in like manner, unfavorable conditions may actually exist in the soil, due to extraneous conditions which would not be indicated in an examination of the samples.

METHOD OF THE MECHANICAL ANALYSIS OF SOILS.

The method used for the mechanical analysis of soils in this Division is Osborne's beaker method, described in the Annual Reports of the Connecticut Experiment Station for 1886 and 1887, with such modifications as experience has suggested for rapid work in the examination of large numbers of samples.

PREPARATION OF THE SAMPLES.

Samples of soil, when received in the laboratory, are spread out in a thin layer and dried at the ordinary temperature of the room. When air dry, they are put into half-gallon preserve jars and stored for future work. In taking a subsample of this for a mechanical analysis, the whole sample is emptied from the jar and thoroughly mixed together on a sheet of heavy manila paper—or better, on a piece of oilcloth. If there are lumps, these are broken with a wooden mallet or with an ordinary wooden rolling-pin. Roots and litter of all kind are thrown away, if they can readily be picked out by hand. Gravel and stones are separated, if present, by passing the material through a brass sieve with circular holes 2 mm. in diameter. These stones are washed, dried, and weighed, and the weight deducted from the original weight of the sample and the percentage of coarse gravel calculated. The portion which has passed through the 2 mm. sieve is called the "fine earth," and is used for the mechanical analysis. The fine earth is thoroughly mixed together, spread out in a thin layer, and a small sample taken from different parts of it and put into a subsample bottle. Twenty grams of this air-dry material are taken for a mechanical analysis and 5 grams for the determination of moisture and organic matter.

METHOD OF DETERMINING THE AMOUNT OF MOISTURE AND ORGANIC MATTER.

Five grams of the air-dry sample are put into a platinum crucible or dish and dried at 110° C. for two hours or to a constant weight. The loss in weight is taken to represent the amount of moisture in the air-dry sample, unless the sample contains a large amount of carbonate of lime, in which case an allowance has to be made for the decomposition of the carbonate, and the moisture determination is very troublesome.

The sample, after being dried to determine the amount of moisture, is

used for the determination of the organic matter. For this purpose it should be subjected to a low red heat until all the organic matter has been oxidized, which can usually be determined by the change of color. The loss in weight during the ignition is taken to represent the organic matter. When there are carbonates present, the sample has to be quite strongly ignited to decompose these completely and the amount of carbonic acid determined in a separate sample.

METHOD OF MECHANICAL ANALYSIS.

It is essential that the mass of soil should be thoroughly disintegrated and the grains separated from each other. This may be accomplished by one of two methods or by a combination of the two.

Twenty grams of soil are moistened with distilled water so as to make a very thin paste. This is gently rubbed in a porcelain mortar with a rubber-tipped pestle until the mass is thoroughly disintegrated and the grains do not cling together. The rubber tip used in this Division is such as is used on crutches and canes, which is easily slipped onto the small end of an ordinary porcelain pestle. In rubbing there should be just enough pressure to detach adhering particles, not enough to break the grains. After pestling for ten or fifteen minutes, more water may be added, and after letting it stand a few moments the turbid liquid may be decanted into a beaker and fresh water added to the soil in the mortar and the pestling continued until a microscopic examination shows that the mass has been thoroughly disintegrated.

Pestling requires a considerable amount of time, and where there are a large number of samples to be done it is much easier to attain the same results by shaking the soils for a long time in water. For this purpose the bottles used in sterilizing milk for infants are very convenient. The 20 grams of soil are washed into such a bottle and the bottle about half filled with distilled water. The bottle is closed with a rubber stopper and put into a shaking machine. The form of shaker used in this Division is very simply constructed. It consists of a box with compartments for holding four tiers of bottles lying on their sides, allowing four bottles in each compartment. This box is supported by chains, attached to the corners, hanging from brackets above. It is fastened by rubber bands to the table below, to steady it, and a guide rod is fastened to the bottom, which works between two uprights to give a true lateral motion to the box. The box is then moved rapidly back and forth by a crank, with a throw of about 5 inches, at a rate of about 170 revolutions per minute. This gives a very good motion to the liquids in the bottles and keeps the soil constantly agitated. Motion may be imparted to the shaker by a water motor or other suitable power. The shaking is continued for from one to two days, according to the nature of the sample. The heavier clay soils require the longer time. The shaking can be done, of course, without any personal attention on the part of the operator, and it is advisable to start the

samples shaking long enough before they are needed, so that there shall be no interruption in the work.

When the shaking is stopped, the contents of the bottles are washed into beakers and the sediment, which quickly subsides, is examined with the microscope. If the disintegration is not complete, a small amount of pestling with the rubber-tipped pestle will finish it. Usually sandy soils are very thoroughly disintegrated after being shaken a day, while clay soils frequently require pestling after having been shaken for two days.

When clean, the grains should show sharp outlines under the microscope, being as a rule quite transparent. Adhering particles make them appear rounded and more or less deeply colored and the outlines indistinct. When pestling alone is resorted to for this disintegration of the material, it may require from fifteen minutes to an hour or more, depending upon the nature of the sample.

When the material is thoroughly disintegrated, it is transferred to a 3-inch beaker, which we may call S. This is filled with water and thoroughly stirred. It is then allowed to settle until all solid particles larger than 0.05 mm. have subsided. This is determined by taking a sample of the turbid liquid from near the bottom of the beaker by lowering a small tube, with the top closed by the finger, to a point just above the sediment, then removing the finger for an instant and letting the liquid enter the tube, closing the tube with the finger again and withdrawing the sample. A drop of this is placed upon a microscope slide and a cover glass placed over it and the particles examined by a good microscope containing an eyepiece micrometer. It is convenient to use a 1-inch eyepiece and a three-fourths and one-fifth inch objective. With the microscope used in this Division the 1-inch eyepiece and $\frac{3}{4}$-inch objective, three of the 0.1 mm. spaces of the eyepiece micrometer measure 0.05 mm. on the stage. With the same eyepiece and the $\frac{1}{5}$-inch objective, two spaces of the micrometer are equal to 0.01 mm., and one space to 0.005 mm. These three values are sufficient for the beaker separations.

When the particles larger than 0.05 mm. have subsided, the turbid liquid is carefully decanted into a larger beaker, M. This turbid liquid contains silt, fine silt, and clay, but no sand if the separation has been properly timed. The sediment in S consists of sand, containing still some silt, fine silt, and clay. This is stirred up with water and again allowed to settle until all the grains of sand have subsided, when the turbid liquid is again decanted into M. This operation is continued until an examination of the sediment in B shows that all particles smaller than 0.05 mm. have been removed. The contents of this beaker B are then washed into a small porcelain dish and evaporated to dryness on the water bath. When dry, this sand may be gently ignited to burn off the organic matter, and when cool it is sifted through a series of sieves which will be described further on.

It is often convenient in separating the silt, fine silt, and clay from the sand to decant before the last portions of sand have settled. This hastens the operation of separating the fine and the coarse material, especially where there is a large mass of sand and but little fine material to be removed. In this case, the turbid liquid which is decanted is put into a separate beaker and the sand which has been poured off is recovered by a further decantation, and when free from all fine material it is added to the sand in the porcelain dish while the latter is evaporating to dryness. The turbid liquid in the beaker M is thoroughly stirred and allowed to settle until a drop taken from near the bottom of the beaker contains no solid particles larger than 0.01 mm., equal to two spaces of the eyepiece micrometer using the $\frac{1}{6}$-inch objective. The turbid liquid, containing only fine silt and clay in suspension, is then carefully decanted into another beaker, P. The sediment remaining in M is again stirred up with water and allowed to settle, and decanted as before. This operation is continued until all particles smaller than 0.01 mm. have been washed out of the sediment in the beaker. Care must be taken in pouring off the turbid liquid that none of the silt goes over, or if it does it must be recovered and added to that in beaker M at some later stage of the operation. The sediment remaining in beaker M should contain nothing larger than 0.05 nor smaller than 0.01 mm. if the separation has been carefully and completely made. This is washed into a platinum dish, evaporated to dryness on the water bath, ignited at a low red heat, cooled in a desiccator, and finally weighed.

The sediment in beaker P containing fine silt and clay is stirred up with water and allowed to settle until everything larger than 0.005 mm. has subsided, as determined by a microscopic examination as before. The turbid liquid, containing only "clay" or material finer than 0.005 mm., equal to one space of the micrometer, is then decanted into a larger beaker, C, of 1 or 2 liters capacity, and the sediment in P repeatedly washed until all of the clay has been removed. When this has been accomplished, the sediment is washed into a platinum dish, evaporated to dryness, ignited, and weighed.

The clay water usually amounts to a number of liters, and to prevent it accumulating to any great extent it is the practice in this Division to measure it in a liter flask and take 100 cc. from each liter to evaporate to dryness. The remainder of the clay solution is thrown away. When the liter flask is full to the mark with the clay solution, care must be taken to thoroughly mix it before taking out the tenth part to be evaporated to dryness. The successive 100 cc. of clay water are poured into a beaker and evaporated in a platinum dish as rapidly as possible. When this clay water has been evaporated to dryness, the sediment is ignited and weighed and the weight multiplied by ten to give the total amount of fine material in the original sample.

In the course of the analysis, several of these grades may be sepa-

rated at once, to facilitate the operation, by the use of additional beakers. It is best to transfer material into smaller beakers as the quantity becomes less in being freed from the finer particles, as this materially hastens the time required for the material to subside.

The sand which was separated in the beginning of the operation and dried and ignited in the porcelain dish is sifted through a series of sieves of the following dimensions: Three round brass sieves 4 inches in diameter are used, which fit into each other and into a cup at the bottom. The top sieve has circular holes 2 mm. in diameter, the second has similar holes 1 mm. in diameter, and the third has holes 0.5 mm. in diameter. These grades are sifted in a very short time.

The material which passes through the lower sieve is then sifted through two grades of bolting cloth—No. 5 and No. 13—having square holes approximately 0.25 mm. and 0.1 mm. in linear dimensions. This sifting requires quite a long time, on account of the fineness of the spaces through which the particles have to pass. It can conveniently be done upon the shaker which is used for the disintegration of the original sample. The two pieces of bolting cloth can be fitted into conveniently arranged brass rings, and the samples should be shaken for an hour or two on this shaker.

Each of these grades of sand are weighed without previous drying, as the amount of hygroscopic moisture is usually inappreciable.

The operation of mechanical analysis is frequently made tedious and sometimes impossible by flocculation. If any tendency to this is discovered, vigorous stirring should be resorted to, and this can best be done with one of the improved forms of egg-beaters found in the market. A small trace of ammonia also assists in overcoming this tendency to flocculation, but it should be added very cautiously, as an excess of ammonia will cause many soils to flocculate. It is a practice in the laboratory of this Division to add 2 or 3 drops of strong ammonia to each sample just before it is put into the shaker. If the sediments are left standing for a length of time, flocculation is liable to occur, and it is very important that the work should be pushed along as rapidly as possible. The operator will find by experience that while waiting on one sediment to subside he may be decanting into extra beakers, which in time may be added to the proper beaker.

The water used in the mechanical analysis should be distilled, if possible, but clear river, well, or hydrant water may be used. In case distilled water is not available, the solid matter in suspension or in solution in the water used should be determined by evaporating 500 cc. of the water to dryness, and igniting and weighing the residue. Allowance should then be made for this residue in the clay determination.

Eight or ten samples can be started at once and can be pushed through about as readily as a single sample. It is not advisable, however, to attempt to carry on more than this number, because the proper attention can not be given to the beakers. A fresh set of samples may

be started on the shaker, however, a day or two before the last set is finished. It requires from six to ten days to complete the analyses of a set of samples if close attention is given to the decantations.

INTERPRETATION OF THE RESULTS.

1. *The texture of soils.*—In the mechanical analysis of soils, it is the practice of this Division to separate the mineral matters into eight grades, according to the diameters of the grains. The number of grains and the diameters have been arbitrarily fixed with respect to the convenience of separation. It would be very desirable, of course, to increase the number of grades, but the practical difficulty of making the separations is so great that the results would not justify the extra time required for the work.

The notes and calculations on the analysis are entered in a book specially designed for this purpose and kept as an original record in the files of the Division. For convenience in referring to the analysis however, the results are copied upon a card upon which the following form is printed. These cards are filed away as in an ordinary card catalogue:

No.... Locality..... Vol.... Page....

Geol. formation..... Crop.....

	Diameter (mm.).	Conventional names.	Per cent.	Remarks.
(1)	2—1	Fine gravel =		
(2)	1—.5	Coarse sand =		
(3)	.5—.25	Medium sand =		
(4)	.25—.1	Fine sand =		
(5)	.1—.05	Very fine sand =		
(6)	.05—.01	Silt =		
(7)	.01—.005	Fine silt =		
(8)	.005—.0001	Clay =		
	Total mineral matter	=		
(9)	Loss at 110° C.	=		
(10)	Loss on ignition	=		
	Total	=		

Analyist,

This gives the bare texture of the soil. In many cases, especially if the type of soil is well known, this is sufficient to indicate the relative relation of the soil to moisture as compared with the typical conditions in the area. With a majority of the soils of the Atlantic Coast States the amount of clay is a very sure indication of the relation of the soils to moisture and of the relative amount of moisture the soil will main-

tain. In the loess soils of the West the amount of silt so far predominates that it determines the relation of the soil to moisture. In the plains marl the amount of very fine sand, ranging from 60 to 75 per cent, determines the relation of the soil to water.

2. *The structure of soils.*—In examining soils from new localities, it is not sufficient to know the kind and size of the grains that form the framework of the soil, for the arrangement of these grains has a very important influence upon the relation of the soil to water. Two soils may have the same texture but maintain very different amounts of water if the grains have a different relative arrangement. One soil may be loamy while the other may be quite impervious to water. This is one of the most important properties of soils, but so far no satisfactory method has been devised for determining with any exactness the arrangement of the grains constituting the structure of the soil. The most promising method is based upon the flow of a fluid through a given volume of soil. Where the grains are evenly distributed in the soil and the spaces between the grains are of nearly uniform size, the resistance to the movement of air or water is at a maximum, while if the grains are unevenly distributed in the soil, as they are in loamy soil, some of the spaces being very much larger than others, the resistance to the movement of air or water is very much less. The method for determining these points has not yet been perfected, as it is very difficult to take a sample of the soil in its natural position in the field of a sufficient size to use for these investigations.

The following table will give an idea of the accuracy which may be expected in the use of this method for the mechanical analysis of soils:

Number.	Description and locality.	Analyst.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			Per et	*Per et*	*Per et*	*Per et*	*Per et*	*Per et*	*Per et*	*Per et*	*Per et*	*Per et*
472	Truck soil from Marley, Md	A	0.14	0.41	0.61	6.66	39.95	32.94	2.73	8.24	2.65	2.71
		B	0.18	0.85	0.60	6.61	42.55	30.82	4.44	6.21	3.18	5.61
937	Limestone soil from Hagerstown, Md	A	4.15	9.86	0.00	0.09	0.56	1.29	1.88	10.23	3.95	68.15
		B	2.62	10.61	0.00	0.11	0.65	1.27	2.51	11.10	4.92	67.52
1803	Plains marl from Agallala, Nebr	A	1.05	3.31	0.00	0.00	0.00	0.99	71.62	13.42	1.43	8.84
		B	1.85	2.76	0.00	0.00	0.02	0.85	71.91	11.66	2.30	10.60
1317	Loess from Virginia City, Ill	A	0.83	4.78	0.00	0.16	0.15	0.18	17.50	65.99	2.13	7.74
		B	0.69	4.42	0.00	0.06	0.11	0.18	31.38	51.37	3.62	9.23
	Mixtures of the above samples.											
I	3 parts truck, 1 part limestone soil[1]	A	0.89	4.51	0.24	6.42	34.41	23.18	2.42	6.82	2.06	19.00
	Calculated[2]	A	1.12	2.76	0.45	5.00	30.08	25.11	2.53	8.73	2.96	19.04
	3 parts truck, 1 part limestone soil[1]	B	0.80	3.91	0.56	6.43	36.03	21.76	2.71	5.35	2.61	21.32
	Calculated[2]	B	0.78	3.28	0.45	4.97	32.05	23.41	3.95	7.42	3.60	21.07
II	2 parts truck, 1 part limestone soil[1]	A	1.30	3.40	0.29	4.42	27.77	25.76	3.34	8.10	2.29	22.67
	Calculated[2]	A	1.46	3.54	0.40	4.47	26.80	22.39	2.44	8.89	3.07	24.51

[1] Actual results of the analysis of the mixtures.

[2] Texture of the mixture calculated from the analyses of the separate samples.

Number.	Description and locality.	Analyst.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Mixtures of the above samples—Continued.		*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*
II	2 parts truck, 1 part limestone soil[1]	B	1.33	3.68	0.27	5.26	30.13	21.78	3.05	6.44	2.89	26.91
	Calculated[2]		0.99	4.09	0.40	4.43	28.57	20.96	3.79	7.84	3.76	26.24
III	1 part truck, 1 part limestone soil[1]	A	1.92	3.76	0.32	4.02	22.45	17.10	2.91	9.34	2.32	34.70
	Calculated[2]		2.14	5.13	0.30	3.37	20.25	17.11	2.30	9.23	3.29	35.42
	1 part truck, 1 part limestone soil[1]	B	1.02	4.87	0.33	4.11	24.60	17.01	2.77	5.55	3.46	36.94
	Calculated[2]		1.40	5.72	0.30	3.35	21.59	16.04	3.47	8.65	4.05	36.56
IV	1 part truck, 2 parts limestone soil[1]	A	2.59	6.70	0.20	2.49	16.23	14.01	2.91	7.25	2.38	44.19
	Calculated[2]		2.74	6.69	0.20	2.28	13.67	11.84	2.15	9.56	3.50	46.32
	1 part truck, 2 parts limestone soil[1]	B	2.63	6.04	0.17	2.46	12.25	14.36	2.82	6.38	3.50	47.21
	Calculated[2]		1.80	7.34	0.20	2.26	14.60	11.11	3.14	9.47	4.34	46.87
V	1 part truck, 3 parts limestone soil[1]	A	2.89	6.54	0.16	1.90	12.14	10.77	3.38	7.74	2.47	49.49
	Calculated[2]		3.12	7.48	0.15	1.72	10.40	9.19	2.09	9.71	3.60	51.76
	1 part truck, 3 parts limestone soil[1]	B	2.89	6.81	0.11	2.80	12.25	13.45	2.78	6.30	4.35	50.12
	Calculated[2]		1.99	8.16	0.15	1.71	11.11	8.63	2.97	9.86	4.48	52.04
V	1 part plains marl, 1 part limestone soil[1]	A	3.11	6.76	0.03	0.09	0.34	1.01	33.05	15.15	2.73	35.85
	Calculated[2]		2.59	6.58	0.00	0.04	0.28	1.13	36.75	11.82	2.68	38.49
	1 part plains marl, 1 part limestone soil[1]	B	2.75	7.93	0.04	0.11	0.36	0.97	37.02	12.10	4.38	35.75
	Calculated[2]		2.23	6.68	0.00	0.05	0.33	1.05	37.20	11.38	3.61	39.06
VII	1 part loess, 1 part limestone soil[1]	A	2.17	4.81	0.00	0.10	0.40	0.75	19.06	32.12	2.61	38.77
	Calculated[2]		2.48	7.32	0.00	0.12	0.35	0.73	9.69	38.10	3.03	37.94
	1 part loess, 1 part limestone soil[1]	B	1.83	8.71	0.00	0.13	0.45	0.76	16.73	31.98	3.26	37.57
	Calculated[2]		1.65	7.51	0.00	0.08	0.37	0.72	16.94	31.23	4.27	38.37

[1] Actual results of the analysis of the mixtures.

[2] Texture of the mixture calculated from the analyses of the separate samples.

Four soils were analyzed by each of two men, A and B. These analyses are given in the first part of the table in such a way that the work of the two men can be directly compared. Then mixtures were made of these different samples and the mixtures analyzed by each of the two men. As a means of giving a double check upon the work, the composition of the mixture was calculated from the results each man obtained in his analyses of the separate samples. The first line of the mixture, therefore, gives the actual results obtained by the analyst, and the second line, distinguished as "Calculated," shows the results which should have been obtained based upon his analyses of the separate samples. This gives a check on the two men and on the work of each one. The samples were all given different numbers, so that neither of the men knew what he was working on. It will be seen that the results do not agree perfectly, but it is considered a very satisfactory piece of work with this method, and is about as accurate work as can be obtained by the use of this method in general laboratory work.

DETERMINATION OF MOISTURE IN ARABLE SOILS.

This Division has begun to keep systematic records of the moisture conditions in some of the principal soil areas of the United States adapted to some of the principal agricultural interests. Records have been undertaken of the moisture conditions in soils adapted to truck, to the different classes and types of tobacco, to wheat, grass, and other staple crops and interests, as well as in soils under different methods of cultivation, especially under irrigation and dry farming in the arid regions of the West.

HOW SAMPLES SHOULD BE TAKEN.

There is at present only one practicable method of determining the amount of moisture in the soil of the field, namely, by taking a sample of soil with a brass tube driven into the soil, withdrawing the sample and drying it completely in the laboratory and determining the loss in weight. As will be seen later, this is not thoroughly satisfactory. The soil-sampling tubes used by this Division are made out of brazed brass tubing about seven-eighths of an inch in internal diameter and 15 inches long. The tubing is No. 21, Stubbs's gauge. In one end a brass collar, about one-fourth of an inch wide, is sweated in. The end of the tube is then turned off in a lathe, giving a rather long taper but letting the point be the full thickness of the collar. A mark is cut into the tube 12 inches from this cutting edge. In the method as used by this Division, the sample is taken by driving the tube down into the soil until the mark on the side of the tube is level with the surface of the surrounding soil. Three inches of the tube is then left exposed with which to withdraw it. The tube should be driven in by quick light taps with a piece of wood, rather than with a piece of metal, to prevent battering the top. The tube is then to be turned in the hole and worked gently back and forth to break off the column of soil from the bottom, when the sample can be carefully withdrawn. Both ends of the tube are then to be immediately covered with rubber caps which fit tightly and prevent any loss of water while the sample is being transported to the laboratory. Rubber finger cots of an appropriate size are conveniently used for these caps, with a rubber "jack-stone ball" forced up snugly into the top of the cot to prevent the tube from cutting the rubber.

ERRORS LIABLE TO OCCUR IN TAKING SAMPLES.

This method of sampling is neither very convenient nor very accurate. In the first place, there is often a marked difference in the texture of a soil within the same field and within a radius of a few feet. This unevenness is often indicated by a difference of color or in the general appearance of the soil. Further, it is impossible to cultivate the soil and leave it in the same physical condition throughout. A man's footstep on a plowed field has been known to make such a difference in the physical condition of the soil as to be plainly apparent in the

development of the crop throughout the season. In plowing or in cultivating or in hoeing, it is not possible to stir the soil and make it fall down in exactly the same way over every part of the field or even over every part of a small plat. The effect of roots also and wormholes, as well as the occurrence of stones and large gravel, modify very materially the physical conditions of the soil in their immediate neighborhood.

The method of sampling itself is liable to errors which even the most careful manipulation will not entirely eliminate. When the brass tube is driven into the ground, there is always some friction on the inside of the tube which tends to compress the soil below the tube, so that the column of soil does not rise to a height inside corresponding to the level of the soil on the outside of the tube. It is to diminish this friction as much as possible that the collar is inserted in the end of the sampling tube so that the core of soil will be a little smaller than the tube. This only diminishes the source of error to a certain extent, and does not entirely eliminate it. The sample usually represents a less depth than it is intended to represent—that is, instead of taking a sample to a depth of 12 inches the sample may only represent in reality a depth of 8 or 9 inches. If the surface soil is drier than the subsoil, then the sample taken will contain less moisture than the average content of the soil to a depth of 12 inches. If the surface soil is wetter than the subsoil, then the sample taken will contain more moisture than the average water content to a depth of 12 inches. If the real depth represented by the sample in the tube varies from day to day on account of this source of error, then the water content of these soils will vary from day to day, or even in samples taken on the same day without any variation in the rainfall.

From these various causes, which can neither be foreseen nor entirely eliminated, it is no unusual thing for samples of soil taken side by side at the same time to vary as much as 3 or 5 per cent in water content.

TIME OF TAKING SAMPLES.

Samples should be taken as nearly as possible at the same time each day. To secure uniformity in the work of different observers, the samples should be taken at 6 o'clock in the evening, or as near that hour as possible, the exact time being stated on the shipping tag. If heavy rain threatens, it is better to take the samples a little early rather than during or after the rain.

DEPTH AT WHICH SAMPLES SHOULD BE TAKEN.

The depth at which the moisture samples should be taken depends somewhat upon the nature of the work. The usual depth is 0 to 12 inches. It is better, when possible, to divide this depth and take two samples at depths of 0 to 3 and 3 to 12 inches, although this nearly doubles the amount of work involved. Occasionally samples should be

taken at less intervals of depth, such as 0 to 3, 3 to 6, 6 to 9, 9 to 12 inches, to give an idea of the distribution of the water in the soil.

Where samples are taken at different depths, the lower samples should be taken from the same hole as the shallower samples. The 0 to 3 inch sample may be taken, then the 3 to 6 inch sampling tube driven down into this same hole, and so on for successive depths. Care must be taken to prevent the surface soil from falling down into the hole between the successive samples.

FORM FOR DESCRIPTION OF SAMPLES.

After taking the sample and putting the rubber caps on the tube, it is to be put into a cloth sack and securely tied and a tag fastened to it. On the tag a form should be printed to be filled out immediately upon taking the sample. The name of sender and locality, and also the date and time of taking the sample, should be given, together with notes as to the character of season and conditions of soil. The following form has been adopted for use in this Division:

Name .....

Post-office ..... State .....

Date .....189.. Time .....o'clock.....M.

Kind of soil ..... Rainfall .....inch..

Too dry.
Condition of soil: Favorable. Remarks:
Too wet.
(Strike out words not meant.) .....

(Note each time this plat is cultivated, weeded, or irrigated, and state how done.)

.....

.....

When a number of samples are to be taken by the same observer each day, it is convenient to put them into sacks of different color, so as to attract attention and lessen the possibility of mixing the samples. The sacks can be conveniently dyed so as to have red, blue, and black, in addition to white sacks. These sacks should be used where samples are taken at different depths, or where samples are taken from different soils or different plats.

CULTIVATION AND CROPPING.

The conditions usually selected for the record of soil moisture are the following:

1. Virgin soil.
2. Grass sod.
3. Uncultivated land which has formerly been cultivated.
4. Cultivated after the method usually practiced in the locality.
   (*a*) Without crops growing on the land.
   (*b*) With crops growing on the land.

5. Subsoiled land.
   (*a*) Without crops growing on the land.
   (*b*) With crops growing on the land.
6. Irrigated fields, either with or without crops.

As no two crops develop in exactly the same way or require the same conditions of cultivation, there is an uncertain factor when plants are growing, which should usually be eliminated in comparative records. It is impossible to have uniformly similar conditions if the soils are cultivated, for they can not be cultivated in exactly the same way and at exactly the same time at different stations, on account of differences in climatic conditions. There is, therefore, an uncertain element when soils are cultivated, which should be eliminated to give the greatest comparative value to the moisture determinations. For these reasons this Division has adopted the practice of taking the moisture conditions in the uncultivated soil, kept free from weeds or growth of any kind, as the basis of comparison between soils of different kinds or in different localities.

It is desirable to know how different methods of cultivation and different crops change these soil conditions, and to this end duplicate determinations may be made in adjoining plats, where these modified conditions of treatment or of crops may be maintained at will.

LOCATION OF PLATS.

The plats from which daily samples are to be taken for the moisture records should be selected with great care and judgment to represent fairly well the type of a considerable area of land for which the records are to be kept. Locate the plats away from fences, trees, buildings, and rich garden spots, and where possible upon a level piece of ground. The plats should be at least 20 feet square, and substantial stakes should be driven at the corners to mark the boundaries of the plat. The soil samples should be taken from this plat during the entire season in a very methodical way. No samples should be taken closer than 3 feet to any side, and they should be taken farther from the side than this if there are deeply rooted plants growing just outside the plat.

In taking the samples, it is well to lay off an imaginary line at least 3 feet from the side of the plat. Take the first sample at one end of this line and, after withdrawing the tube, fill up the hole with loose soil and stick in a small peg to mark the spot. A piece of broom handle will answer well for this purpose. The sample for the next day should be taken about a foot away from the peg, on the line which has been established, and after filling up this hole the peg should be removed to mark the spot where the last sample was taken. In this way continue in a straight line across the plat, never getting nearer than 3 feet to any of the sides. After one row is finished, begin a second row a foot away from the first. With this methodical manner all danger of taking two samples from the same hole is avoided and the influences of the

previous sampling upon the conditions of the soil are reduced to a minimum.

In taking samples, avoid walking on the part of the plat not sampled. If the plat is likely to be trampled upon, stretch stout cords or wires around the stakes at the corners. If the plat is to be cultivated with the rest of the field, the cords can be let down to permit of the cultivation. Unless crops are purposely grown upon the plat, the soil is to be kept free from weeds or vegetation of any kind. On the cultivated plat this may be done either by pulling the weeds or by cutting them off with a sharp hoe, stirring the ground as little as possible.

HOW THE PLATS SHOULD BE TREATED.

1. *Virgin soil.*—Lay off the plat as described above, leaving the natural vegetation and noting the character of the vegetation and the stage of growth at frequent intervals during the season.

2. *Grass sod.*—The grass should be allowed to grow as on the rest of the field, and cut at the proper time. If it is in a pasture, the stock should be allowed to graze on it as on the rest of the field, as the same conditions should be maintained on all parts of the field. The sample should be taken by pushing aside the grass or by pulling up a small tuft of grass. As little trash, stubble, grass, or roots should be taken in the sample as possible. Reports should be made at least weekly of the height of the grass, stage of growth, dates of cutting, or the condition of the pasture.

3. *Uncultivated land.*—This plat should be upon land which has recently been cultivated. In preparing for the work, the surface should be leveled off in as even and uniform a manner as possible. It should not be cultivated, however, during the season, except such cultivation as may be necessary to keep the surface free from weeds. In the preliminary report the length of time should be stated since the soil has been cultivated, as well as the character of cultivation and the kind of crop used at that time.

4. *Cultivated land.*—If the effect of cultivation alone upon the water content of the soils is to be studied, the plat should be cultivated in the same way and at the same time as the rest of the field, and in strict accordance with the prevailing practice of the locality. If the staple crop is grown on ridges or hills, throw up similar ridges or hills and cultivate as though plants were actually growing on the plat. Take the samples from the crest of the ridges, in the places the plants would occupy if a crop had been planted. The time and manner of cultivation should be noted.

5. *Subsoiled land.*—In studying the effect of subsoiling on the water content of soils, the same general directions should be followed as given under paragraph 4. The plat may or may not be subsequently cultivated, and it may or may not have plants growing upon it, according to the purpose of the investigation. The subsoiling should be done

in all cases a sufficient length of time before the observations begin so as to insure a soaking rain, which shall put the subsoiled land in good condition and compensate for the drying effect of the subsoiling.

6. *Irrigated land.*—The object of irrigation is to maintain, through the artificial application of water, uniform conditions of moisture, or conditions better adapted to the proper development of crops. The necessity for this is not confined to the soils of the arid regions, but wherever, through the vicissitudes of the season, the moisture supply in the soil falls below a certain minimum amount below which crops suffer water should, if practicable, be applied to the soil as a means of preventing serious damage to the crop.

The irrigated plat should be laid off as are the others, and the samples should be taken in the same way. In the method and the time of

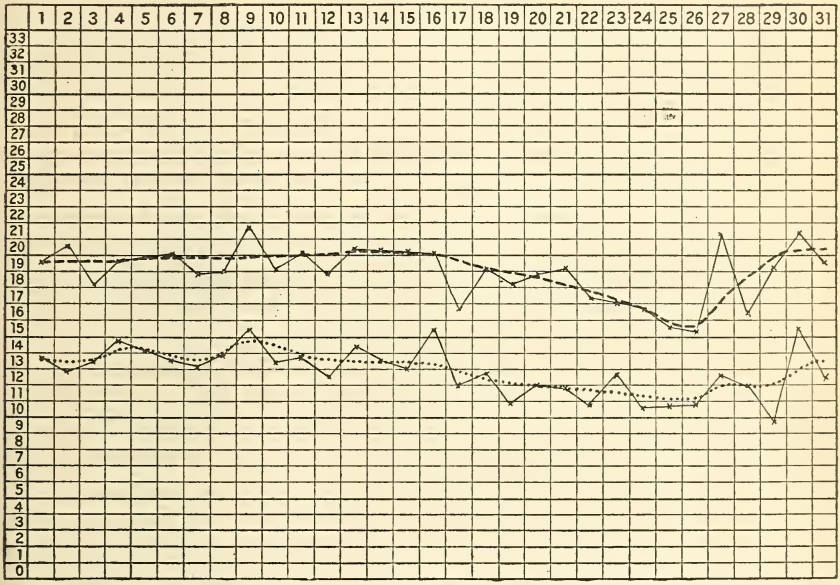

FIG. 1.—Curves showing the moisture content of two tobacco soils of the Connecticut Valley, July, 1895.

the application of water the local practice may be pursued, or any modification of this which suggests itself to the investigator as likely to be of some practical value. Weekly reports should be made of the time, mode, and extent to which the soil has been thus artificially supplied with water.

A diagram is given showing how the results of the daily moisture determinates are platted. The records are from two tobacco soils of the Connecticut Valley.

In the illustration the horizontal lines running across the page represent the per cent of water in the soil, ranging from 0 to 33 per cent, as indicated by the figures on the left-hand side. The vertical lines extending from top to bottom of the diagram mark off spaces corresponding

to the days of the month. In platting the curve the per cent of water on each successive day is indicated by a small dot placed in the column corresponding to that day at a height corresponding to the per cent of moisture, as indicated by the figures on the left-hand side of the diagram. These points, representing the actual moisture determinations, are connected with a faint line, usually making a zigzag line across the chart, having somewhat the appearance of the edge of a cross-cut saw.

The meteorological conditions were very uniform over a considerable part of the month, so that much of the daily variations shown must be due to errors of determination. Some of the results are probably too high and others are too low. To eliminate these errors so far as possible, a heavy line is drawn across the chart midway between the observations, so as to occupy a mean position in respect to them. This line is usually a curved line, the curvature of which depends upon the occurrence of rain and the amount of evaporation. This line more truly represents the amount of water in the soil for any particular day or number of days than the actual results of the moisture determinations.

It is hoped that in a short while a more convenient and much more accurate method of determining the amount of moisture in the soil of a field will be so far perfected that it can be adopted by the Department. This is based upon the fact that a moist soil is a much better conductor of electricity than a dry soil. When this electrical method is perfected, it will be fully described and instructions prepared for the use of the instruments.

The soil appears to be a lifeless, inert material, but it is in reality full of life and movement. It is so extremely sensitive that any difference in the cultivation or cropping changes the physical properties of the soil and the relation of the soil to the rainfall. This gives a very important control of the water supply of plants through different methods of cultivation. It makes it necessary also that samples of soil for moisture determinations from different soils or from different parts of the country, to have any comparative value as records, be taken under as nearly as possible the same conditions of treatment.

METHOD OF DETERMINING THE AMOUNT OF MOISTURE IN THE SAMPLES.

When the samples are received in the laboratory, the information contained on the shipping tag is at once entered in an appropriate book. The rubber caps are then taken off and the soil pushed out and thoroughly and quickly mixed by hand upon a piece of oilcloth or manila wrapping paper. A suitable quantity is then put into an aluminum dish so that when loosely packed the dish is about full. The dishes used by this Division are 3 inches in diameter and three-fourths of an inch deep. They hold from 75 to 100 grams of soil, according to the way in which the soil is packed. It is convenient to have the aluminum dishes brought to the same weight by filing the heavier ones,

so that the dishes do not need to be weighed for each determination. The weight of dish and fresh soil is taken as quickly as possible, and they are then put into a drying oven with a temperature regulator to keep the temperature uniformly 110° C. The samples are dried at this temperature for at least twenty hours, when they are again weighed and the loss of weight calculated in per cent of the original samples. The time required for the sample to attain a constant weight depends largely upon the nature of the soil and should be determined by preliminary trials at the start.

In publishing a table of the moisture determinations, it is better to take the figures from the curves which have been platted as already indicated, as this gives more truly the average daily amount of water in the soil than the actual determinations.

There are at least three ways of stating the results of the moisture determinations—in per cent of the moist soil, in per cent of the dry soil, and in parts per unit volume. The results will not appear to agree when calculated in these several ways, for there is no uniform basis of calculation except in the last case. When 100 grams of moist soil are dried until all the water is expelled, the loss in weight indicates the amount of water attached to the soil grains. This may be calculated in per cent of the original sample or may be expressed by comparing it with the weight of the dry soil. If the actual weight of water in 100 grams of moist soil was twice as great one time as another, the per cent of water would not be quite twice as great if figured on the fresh weight as with the smaller amount of water. If the water present is figured in per cent of the weight of dry soil, then, if there is twice as much water present in the soil one day as on another, the per cent of water will be twice as great. This method of expressing the results is rather better, therefore, where the fluctuations of the water of any particular field are to be studied, for twice the per cent always means twice the amount of water contained in the soil. This does not hold good, however, when different soils are compared, on account of the difference in weight of a unit volume of different soils. In other words, the same amount of rainfall does not give the same per cent of moisture in different soils by either method of calculation.

The following table illustrates this:

Soil.		First inch of rain.	Second inch of rain.	Third inch of rain.	Fourth inch of rain.	Fifth inch of rain.
Clay land:						
80 pounds per cubic foot	dry	6.5	13.0	19.5	26.0	32.5
	wet	6.1	11.5	16.3	20.6	24.5
Sand:						
100 pounds per cubic foot	dry	5.21	10.4	15.6	20.8	26.0
	wet	4.95	9.4	13.5	17.25	20.7

Assume that a clay land weighs 80 pounds per cubic foot, which is an average weight for a strong clay land, and that a sandy soil weighs

100 pounds per cubic foot. An equivalent of an inch in depth of rain is added to each of these cubic feet of soil. This will make 6.5 per cent of water in the clay land, calculated on the dry weight, and 5.2 per cent in the sandy land. If a second inch of water is added to these moist soils, there will be 13 per cent in the clay land and 10.4 per cent in the other. When the fifth inch of water has been added to the soils, there will be 35.5 per cent of water present, if figured on the dry weight, and this is just five times the percentage that was present when 1 inch had been added. If expressed in percentage of the moist soil, this would only be 24.5 per cent. This is considerably less than five times the percentage after the first inch had been added. Similarly, when the same quantity of water is added to the sandy soil, there will be 26 per cent and 20.7 per cent, respectively, if calculated on the dry or fresh weight of soil. On account of the difference in weight of the cubic feet of soil, 5 inches of rainfall will give 32.5 per cent if calculated on the dry weight of the clay soil, and 26 per cent in the sand. An equal percentage of water in different soils does not therefore necessarily mean an equal amount or weight of water in the soils. As more water is added, the difference continues to be more apparent, for with the increase in weight of the cubic foot of moist soil the successive amounts of water do not increase the percentage to the same extent.

It would be very much better if the amount of water could be expressed in unit volumes of the soil; that is, if the amount per cubic foot could be given. This would be strictly comparable, not only in the same soil but in all soils. The trouble is that the weight of a cubic foot of the soils would have to be determined for every individual case, and this is a difficult matter to determine, even under the most favorable circumstances.

It has been the practice in this Division to express the results of the moisture determination in per cent of the original sample; that is, to state that the soil on a certain day contained in its moist condition a certain percentage of water.

After the results have been calculated, it is advisable to plat them, as already explained, for the graphic representation of the variations which have occurred. It is very advisable also in publishing the results to take the data from this chart rather than to use the original figures, because this averages the results and eliminates or diminishes many of the errors of determination.